

Title	A weak basis theorem for Σ^1_1 sets of positive measure (Set theory of the reals)
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Citation	数理解析研究所講究録 (2000), 1143: 55-59
Issue Date	2000-04
URL	http://hdl.handle.net/2433/63898
Right	
Type	Departmental Bulletin Paper
Textversion	publisher

A weak basis theorem for Π_2^1 sets of positive measure

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Abstract

We give a weak basis result for Π_2^1 sets of positive measure, which is closely related to our previous paper [2] in which we have assumed the existence of 0^\sharp .

This note is devoted to the following

Theorem 1 *Let $s \in 2^\omega$ be a real such that \aleph_1^L is a recursive-in- s ordinal. Then every Π_2^1 set of positive measure contains a $\Delta_1^1(s)$ member.*

This theorem is closely related to the main theorem of our previous paper [2]: if 0^\sharp exists, then every Π_2^1 set of positive measure contains a member which is arithmetical in 0^\sharp . Indeed, letting $s = 0^\sharp$ the hypothesis of our present theorem is achieved and this almost (but not literally) proves our older theorem. The hypothesis in the present result is weaker than that of the “ 0^\sharp version.” Therefore, it seems to be applicable to wider context — See Section 3 for some discussion on L -generic models in which there is a Π_2^1 singleton s satisfying the hypothesis of Theorem 1.

1 Tools

Let us fix, once for all, a recursive bijection between $\omega \times \omega$ and ω . By the notation $\langle i, j \rangle$ we mean both the ordered pair and the integer which is assigned to this ordered pair by the fixed bijection. Each real $r \in 2^\omega$ codes a binary relation \leq_r defined as

$$i \leq_r j \iff r(\langle i, j \rangle) = 1$$

Let **WO** be the set of reals $r \in 2^\omega$ such that \leq_r well-orders ω . For $r \in \mathbf{WO}$, let $\|r\|$ be the order-type of the wellordering \leq_r . A countable ordinal ξ is said to be recursive-in- a if $\xi = \|r\|$ for some real $r \in \mathbf{WO}$ which is recursive in a .

The smallest ordinal which is not recursive-in- a is denoted by ω_1^a . Then ω_1^a equals the smallest ordinal $\xi > \omega$ such that the structure $(L_\xi(a), \in, a)$ is

admissible. A real x is hyperarithmetical in a if and only if it is $\Delta_1^1(a)$ if and only if it belongs to $L_{\omega_1^a}(a)$.

For a countable ordinal ξ let $\mathbf{WO}(\xi)$ be the set of $r \in \mathbf{WO}$ with $\|r\| < \xi$. For each countable ξ , the set $\mathbf{WO}(\xi)$ is Borel. Indeed we have:

Lemma 1.1 *Let $s \in 2^\omega$. Let ξ be a recursive-in- s ordinal. Then $\mathbf{WO}(\xi)$ is a $\Delta_1^1(s)$ set.*

Proof. Let $r \in \mathbf{WO}$ be a real which is recursive in s and satisfies $\xi = \|r\|$. Then a real x belongs to $\mathbf{WO}(\xi)$ if and only if there is an order-preserving mapping of (ω, \leq_x) into an initial segment of (ω, \leq_r) , if and only if $x \in \mathbf{WO}$ and there is no order-preserving mapping of (ω, \leq_r) into (ω, \leq_x) . This gives a $\Delta_1^1(r)$ characterization of $\mathbf{WO}(\xi)$. \square

Let $s \in 2^\omega$ be a real such that \aleph_1^L is a recursive-in- s ordinal. This readily implies \aleph_1^L is countable. Under this assumption, every Π_2^1 set of reals is Lebesgue measurable. The main theorem is proved by examining how this measurability is realized in a certain effective way. To this end, we need two $\Delta_1^1(s)$ sets: Lemma 1.1 implies that the set $\mathbf{WO}(\aleph_1^L)$ of codes of constructibly countable well-ordering is $\Delta_1^1(s)$. Next we see that there is a $\Delta_1^1(s)$ set C of measure one consisting of random reals over L .

For a real $t \in 2^\omega$ and an integer $n \in \omega$, let $(t)_n$ be the real defined by: $(t)_n(i) = t(\langle n, i \rangle)$. Each real codes a countable sequence of reals in this way.

Lemma 1.2 *There is a $\Delta_1^1(s)$ real t such that*

$$\{(t)_n : n \in \omega\} = 2^\omega \cap L.$$

Proof. For $2^\omega \cap L = 2^\omega \cap L_{\aleph_1^L}$, this set belongs to $L_{\omega_1^s}[s]$, the smallest admissible set containing s . Since $L_{\omega_1^s}[s]$ models "every set is countable," there exists in it a surjection $f : \omega \rightarrow 2^\omega \cap L_{\aleph_1^L}$. Let $t(\langle n, i \rangle) = f(n)(i)$. \square

Let $U \subset 2^\omega \times 2^\omega$ be a Π_2^0 set which is universal for Π_2^0 . Let t be a real as in Lemma 1.2. Let $C \subset 2^\omega$ be the following set

$$\begin{aligned} C &= \{x \in 2^\omega : (\forall y \in 2^\omega \cap L)[\mu(U_y) = 0 \implies x \notin U_y]\} \\ &= \{x \in 2^\omega : (\forall n)[\mu(U_{(t)_n}) = 0 \implies x \notin U_{(t)_n}]\}. \end{aligned}$$

where μ denotes the Lebesgue measure. Then C is a $\Delta_1^1(s)$ set such that $\mu(C) = 1$.

Lemma 1.3 *Every $x \in C$ is random over L . Consequently the equality $\aleph_1^{L[x]} = \aleph_1^L$ holds for all $x \in C$.* \square

2 Reducing Π_2^1 sets to $\Pi_1^1(s)$

Let P be a Σ_2^1 set of reals, then there is a recursive function $f : 2^\omega \times 2^\omega \rightarrow 2^\omega$ such that

$$x \in P \iff (\exists y)[f(x, y) \in \mathbf{WO}].$$

By the Shoenfield Absoluteness Lemma, it is equivalent to say

$$x \in P \iff (\exists y \in 2^\omega \cap L[x])[f(x, y) \in \mathbf{WO}].$$

In such a case, we have $f(x, y) \in L[x]$. So $\|f(x, y)\| < \aleph_1^{L[x]}$. It follows that

$$x \in P \iff (\exists y \in 2^\omega \cap L[x])[f(x, y) \in \mathbf{WO}(\aleph_1^{L[x}])].$$

By these observations, we have:

Lemma 2.1 *Let P be a Σ_2^1 set of reals, then there is a recursive function $f : 2^\omega \times 2^\omega \rightarrow 2^\omega$ such that*

$$x \in P \iff (\exists y)[f(x, y) \in \mathbf{WO}(\aleph_1^{L[x}])].$$

Now let A be a Π_2^1 set of reals. Put $P = 2^\omega \setminus A$, then by Lemmas 1.3 and 2.1, there is a recursive function $f : 2^\omega \times 2^\omega \rightarrow 2^\omega$ such that

$$x \in C \implies [x \in A \iff (\forall y)[f(x, y) \notin \mathbf{WO}(\aleph_1^L)]].$$

Therefore we have

Lemma 2.2 *Let A and f as above. Then*

$$A \cap C = \{x \in 2^\omega : x \in C \ \& \ (\forall y)[f(x, y) \notin \mathbf{WO}(\aleph_1^L)]\}.$$

Consequently, $A \cap C$ is a $\Pi_1^1(s)$ set.

If A has positive Lebesgue measure, so is $A \cap C$, for C contains almost all reals. Being a $\Pi_1^1(s)$ set of positive measure, $A \cap C$ contains a $\Delta_1^1(s)$ real by the Sacks-Tanaka Basis Theorem ([4], Chap.IV, 2.2). Thus we have proved the main theorem.

3 Some remarks

Theorem 1 would be of no interest unless there exists a definable real which makes \aleph_1^L countable. The simplest way to make \aleph_1^L countable is to add to L a generic function on ω onto \aleph_1^L by forcing with finite partial functions. This forcing adds no ordinal-definable reals. Hence in the generic extension the non-constructible reals form a Π_2^1 set of positive measure which does not contain any ordinal-definable real.

Much finer method to force \aleph_1^L countable have been invented by Jensen and Solovay. In [3] they give a forcing notion $\mathcal{P} \in L$ and a Π_2^1 formula φ such that if $G \subset \mathcal{P}$ is generic then there exists a real $a \in V[G]$ such that

1. $L[a] \models (\forall x \subset \omega)[\varphi(x) \iff x = a]$;
2. every constructible real is recursive in a .

Clause 2 implies that the real a is non-constructible. Hence, in $L[a]$, a is a non-constructible Π_2^1 singleton. (See Theorem B of [1] for a yet sharper result along this line.)

Now let a be as above and $s = \mathcal{O}^a$, the hyperjump of a . That is to say, s is the set of notations of constructive ordinals relative to a . (See Chapter I of [4]. If you are not familiar with theory of hyperarithmetic hierarchy, you can use here the set $\{e \in \omega : \{e\}^a \in \mathbf{WO}\}$ instead of \mathcal{O}^a .) Since every ordinal below \aleph_1^L is recursive-in- a , we have $\aleph_1^L \leq \omega_1^a < \omega_1^s$. In $L[a]$, on the other hand, s is a Π_2^1 singleton for, in $L[a]$,

$$x = s \iff (\forall y)[y = \{e_0\}^x \implies \varphi(y) \& x = \mathcal{O}^y],$$

where e_0 is a universal Gödel number which retrieves y from \mathcal{O}^y . Thus in the Jensen-Solovay model, there is a Π_2^1 singleton s such that \aleph_1^L is a recursive-in- s ordinal:

Theorem 2 *There is a model of ZFC in which \mathcal{O}^\sharp does not exist while every Π_2^1 set of reals is Lebesgue measurable and every positive-measure Π_2^1 set contains Δ_3^1 members.*

In this model, however, exists a Δ_3^1 real r such that there exists a non-measurable $\Pi_2^1(r)$ set. Can we somehow multiply the Solovay-Jensen method to obtain an L -generic model of: *For every real r every $\Pi_2^1(r)$ set is Lebesgue measurable and if it has positive measure then it contains $\Delta_3^1(r)$ members?*

Our hypothesis of Theorem 1 “ \aleph_1^L is a recursive-in- s ordinal” seems quite essential, for otherwise $\mathbf{WO}(\aleph_1^L)$ is not a $\Sigma_1^1(s)$ set. We do not know whether this hypothesis can be weakened to “every ordinal below \aleph_1^L is recursive in s ,” or equivalently, “every constructible real is $\Delta_1^1(s)$.” Let us note here that this condition is strictly weaker than the one in Theorem 1:

Theorem 3 *There is a real $s \in 2^\omega$ in which every constructible real is recursive whereas \aleph_1^L is not a recursive-in- s ordinal.*

Proof. A model $\mathcal{M} = (M, \in_M)$ of set theory is called an ω -model if all \mathcal{M} -integers are standard. Let us say an ω -model \mathcal{M} to be nice if $M = \omega$ and the natural sequence $\langle (n)^\mathcal{M} : n \in \omega \rangle$ of the \mathcal{M} -integers is recursive in the real world. Every countable ω -model has an isomorphic copy which is nice.

Let $a \subset \omega$ be a real such that $\aleph_1^L = \omega_1^a$. Then let Ψ be the set of reals $r \in 2^\omega$ which codes the \in -relation of a non-wellfounded nice ω -model of KP set theory in which an instance of a exists. Then Ψ is a non-empty $\Sigma_1^1(a)$ set. Therefore by the Gandy Basis Theorem (see, [4] Chap.III, 1.5), there is an $s \in \Psi$ such that $\omega_1^{(a,s)} = \omega_1^a = \aleph_1^L$.

Let M be the model coded by s . Since M contains an instance of a , it follows that $\omega_1^a \leq \omega_1^s$. Hence $\omega_1^s = \aleph_1^L$. Each non-standard ordinal in M has order type $\omega_1^s \times (1 + \text{OrderType}(\mathbb{Q}, <)) + \rho$ for some $\rho < \omega_1^s$. Therefore for each ordinal $\xi < \omega_1^s$ the set L_ξ is isomorphic to an initial part of the constructible hierarchy

in M . It follows that M contains instances of all sets in $L_{\aleph_1^L}$. From this it follows that every constructible real is recursive in s . \square

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